UNCLASSIFIED

WEIDLINGER ASSOCIATES

110 EAST 59TH STREET

NEW YORK, NEW YORK 10022

524484

ON IMPROVING AND EXTENDING THE DESIGN SHOCK SPECTRA USED IN DDAM

by

Frank L. DiMaggio and David Ranlet

TECHNICAL NOTE

SEPTEMBER 1976

OFFICE OF NAVAL RESEARCH
CONTRACT NO. N00014-72-C-0119

This project is sponsored by the joint DNA/ONR/NAVSEA program in "Advanced Submarine Shock Survivability in Underwater Nuclear Attack."

ABSTRACT

A method is presented which may be used to improve and extend the design shock spectra used in the Dynamic Design Analysis Method (DDAM).

I INTRODUCTION

The Dynamic Design Analysis Method (DDAM), introduced by Belsheim and O'Hara of the Naval Research Laboratory, Ref. [1], requires design shock spectra as inputs. To date, these values have been obtained from a limited number of test results and their applicability is limited to very heavy internal components. It is the purpose of this note to indicate how this limitation can be relaxed and how the presently used spectra can be improved.

II SUMMARY OF NORMAL MODE THEORY ON WHICH DDAM IS BASED

This section is a summary of the presentation of O'Hara and Cunniff, Ref. [2], with some changes in notation. Generalization to more than one-dimensional motion is straightforward, as demonstrated, e.g., by Cunniff and O'Hara, Ref. [3].

Consider a one-dimensional, n degree of freedom system, S, like the 2 degree of freedom system shown in Fig. 1, subjected to a base acceleration $\ddot{z}$. In what follows, the generic displacement of the i-th mass M_i will be denoted by $x_i(t)$. The subscript j, like i, will refer to a mass point.

Let ω_a , a = 1, 2,...n, denote the a-th fixed-base natural frequency of S, and let c_{ia} denote the displacements of the masses M_i in the a-th principal mode, as shown in Fig. 2. The relative displacement of M_i with respect to the base, denoted by

$$y_i = x_i - z \tag{1}$$

may then be expressed as

$$y_i = \sum_a y_{ia} = \sum_a q_a c_{ia} \tag{2}$$

in which the q_a are generalized coordinates.

For zero initial conditions,

$$q_a = - \frac{\sum_i M_i c_{ia}}{\sum_i M_i c_{ia}^2} \frac{V_a}{\omega_a^2} \tag{3}$$

in which

$$V_a(t) = \omega_a \int_0^t \ddot{z}(\tau) \sin \omega_a(t - \tau)d\tau \tag{4}$$

The generalized accelerations are

$$\ddot{q}_a = \frac{\sum_i M_i c_{ia}}{\sum_i M_i c_{ia}^2} (V_a - \ddot{z}) \tag{5}$$

The contribution to the displacement x_i from the a-th mode then becomes

$$x_{ia} = \frac{c_{ia} \sum_j M_j c_{ja}}{\sum_j M_j c_{ja}^2} (z - \frac{V_a}{\omega_a^2}) \tag{6}$$

and

$$\ddot{x}_{ia} = \frac{c_{ia} \sum_j M_j c_{ja}}{\sum_j M_j c_{ja}^2} V_a \tag{7}$$

The contribution to the base reaction from the a-th mode may be obtained by considering the contribution to the motion of S of the a-th mode. If inertia is replaced by equivalent (d'Alembert) body forces, the equilibrium free body diagram of Fig. 3 permits the determination of the contribution of the a-th mode to the reaction on the base of S as

$$R_a = \sum_i M_i \ddot{x}_{ia} = \frac{[\sum_i M_i c_{ia}]^2}{\sum_i M_i c_{ia}^2} V_a \tag{8}$$

Letting

$$\frac{[\sum_i M_i c_{ia}]^2}{\sum_i M_i c_{ia}^2} \equiv M_a \tag{9}$$

denote the a-th effective modal mass, the base reaction becomes

$$R_a = M_a V_a \tag{10}$$

M_a is the mass of a simple oscillator, of frequency ω_a, producing the same base reaction, R_a, as that contributed by the a-th mode. It can be shown that

$$\sum_a M_a = \sum_i M_i \tag{11}$$

III APPLICATION TO DDAM

The total base reaction on S can be obtained by adding the modal contributions of Eq. (10), i.e.,

$$R = \sum_a R_a = \sum_a M_a V_a \tag{12}$$

if the base motion z(t) is known and the structure S modeled such that frequencies ω_a and modal masses M_a can be determined*)

DDAM provides an approximation to Eq. (12), motivated by the impossibility, at the time of its formulation, of obtaining reliable analytical or experimental values for the base motion z(t) of shells, containing internal structures, to shock loading. The best that could be done was to specify, on the basis of a limited number of tests, the maximum value of $|V_a|$ as a function of modal frequency ω_a . The plot of $|V_a|_{max}$ as a function of ω_a is referred to as a design shock spectrum. An illustrative example is shown in Fig. 4.

Using such a spectrum, a conservative design value for the base reaction of Eq. (12) may be obtained as

$$R \simeq \sum_a M_a \, |V_a|_{max} \tag{13}$$

or more refined statistical measures, e.g., root mean square values, could be used.

The limited test results available allowed design shock spectra to be constructed only for very heavy internal components.

---

*) Similar series expressions for the total displacements, relative displacements and spring forces may be readily written.

IV IMPROVING AND EXTENDING THE RANGE OF APPLICABILITY OF DDAM

In a series of reports, Refs. [4]-[6], Weidlinger Associates has proposed an analytical method, programmed for high-speed digital computers, which produces, as a part of its output, the function z(t) for shock loading of finite-length shell structures with internal components. This method of analysis has been used to make excellent predictions of tests on submerged shells containing internal structure conducted in Chesapeake Bay by UERD, Ref. [7]. This program has been continued, and there is every indication that much more complex structures subjected to shock loading will soon be capable of successful analysis.

The analytical method developed by Weidlinger Associates can be used to develop improved design shock spectra, by calculating maximum values of $|V_a|$ using Eq. (4). It is suggested that results first be obtained for those combinations of input and structure for which DDAM is now considered applicable, as check points, and then to fill in the range where DDAM is presently not used.

REFERENCES

[1] Belsheim, R.O. and O'Hara, G.J., "Shock Design of Shipboard Equipment, Part 1 - Dynamic Design-Analysis Method", NRL Report 5545, U.S. Naval Research Lab., Washington, D.C., September 16, 1960.

[2] O'Hara, G.J. and Cunniff, P.F., "Elements of Normal Mode Theory", NRL Report 6002, U.S. Naval Research Lab., Washington, D.C., November 15, 1963.

[3] Cunniff, P.F. and O'Hara, G.J., "Normal Mode Theory for Three-Directional Motion", NRL Report 6170, U.S. Naval Research Lab., Washington, D.C., January 5, 1965.

[4] Bleich, H.H., DiMaggio, F.L., Baron, M.L. and Ranlet, D., "Transient Response of Submerged Shells of Finite Length to Full Envelopment Type Shock Waves, Part I: Acoustic Approximations for Uncoupling Fluid-Structure Interaction Problems", Technical Report No. 13, Weidlinger Associates, New York, New York, Office of Naval Research, Contract N00014-72-C-0119, July 1974.

[5] Ranlet, D. and McCormick, J.M., "Transient Response of Submerged Shells of Finite Length to Full Envelopment Type Shock Waves, Part II: Comparison of Predictions and Measured Test Results for Side-On Loading", Technical Report No. 14, Weidlinger Associates, New York, New York, Office of Naval Research, Contract N00014-72-C-0119, April 1974.

[6] DiMaggio, F.L. and Ranlet, D., "Transient Response of Submerged Shells of Finite Length to Full Envelopment Type Shock Waves, Part III: Forced Motion when Elastic Structures Are Attached Internally", Technical Report No. 16, Weidlinger Associates, New York, New York, Office of Naval Research, Contract N00014-72-C-0119, November 1974.

[7] Ranlet, D., Bleich, H.H., DiMaggio, F.L. and Baron, M.L., "Transient Response of Submerged Shells of Finite Length to Full Envelopment Type Shock Waves, Part IV: Comparison of Predicted and Measured Results for Side-On Loading of a Shell Containing Internal Structure-Configuration 1", Technical Report No. 17, Weidlinger Associates, New York, New York, Office of Naval Research, Contract N00014-72-C-0119, December 1974.

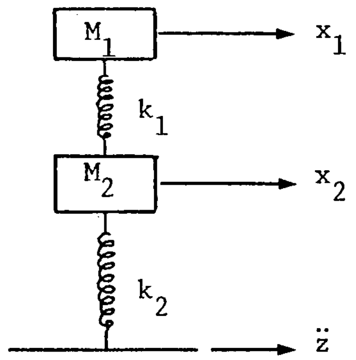

Fig. 1

System S

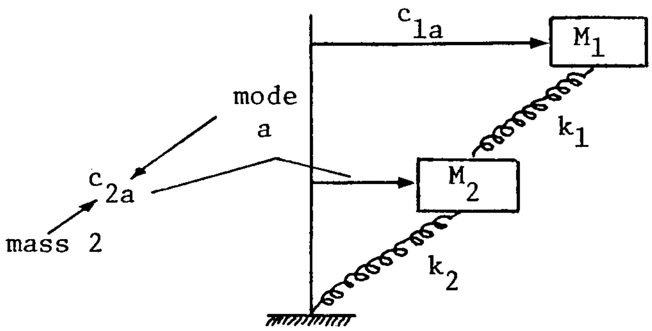

Fig. 2

a-th Principal Mode of S

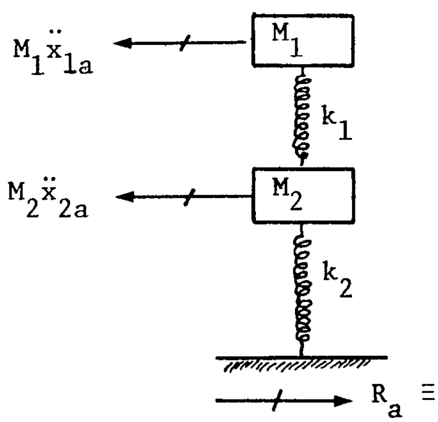

Fig. 3

Free Body Diagram for Determining Contribution to Base Reaction from a-th Mode

Base Reaction on Component S (a-th Mode)

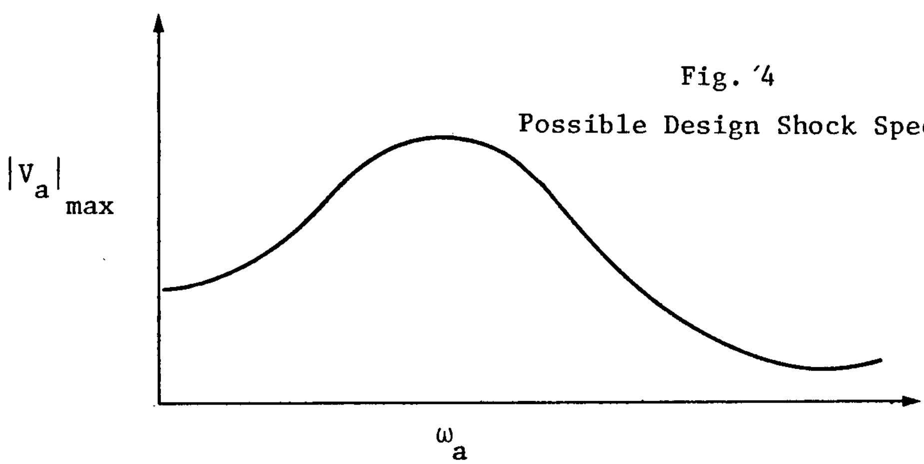

Fig. 4

Possible Design Shock Spectrum

ASSISTANT TO THE SECRETARY DEFENSE
ATOMIC ENERGY
WASHINGTON , DC 20301
ATTN DONALD COTTER

DIRECTOR
DEFENSE ADVANCED RSCH PROJ AGENCY
ARCHITECT BUILDING
1400 WILSON BLVD
ARLINGTON VA. 22209
ATTN A TACHMINDJI
ATTN STO KENT KRESA
ATTN TECHNICAL LIBRARY
ATTN R CHAPMAN

DIRECTOR
DEFENSE INTELLIGENCE AGENCY
WASHINGTON D.C. 20301
ATTN DI-7D E. OFARRELL
ATTN DI-7E
ATTN DT-1C J. VERONA
ATTN DT-2 WPNS + SYS DIV
ATTN TECHNICAL LIBRARY

DIRECTOR
DEFENSE NUCLEAR AGENCY
WASHINGTON D.C. 20305
ATTN STTL TECH LIBRARY (2 COPIES)
ATTN STST ARCHIVES
ATTN DDST
ATTN SPSS (2 COPIES)

CHAIRMAN
DEPT OF DEFENSE EXPLO SAFETY BOARD
RM-GB270, FORRESTAL BUILDING
WASHINGTON D.C. 20301
ATTN DD/S+SS

DIR OF DEFENSE RSCH + ENGINEERING
WASHINGTON D.C. 20301
ATTN AD/SW
ATTN DD/TWP
ATTN DD/S+SS
ATTN AD/NP

COMMANDER
FIELD COMMAND
DEFENSE NUCLEAR AGENCY
KIRTLAND AFB, NM 87115
ATTN FCTA
ATTN FCTA-D

INTERSERVICE NUCLEAR WEAPONS SCHOOL
KIRTLAND AFB, NM 87115
ATTN TECH LIB

DIRECTOR
JOINT STRAT TGT PLANNING STAFF JCS
OFFUTT AFB
OMAHA, NB 68113
ATTN STINFO LIBRARY

WEAPONS SYSTEMS EVALUATION GROUP
400 ARMY NAVY DRIVE
ARLINGTON VA 22202
ATTN DOC CON

CHEIF OF RES, DEV + ACQUISITION
DEPARTMENT OF THE ARMY
WASHINGTON D.C. 20310
ATTN TECHNICAL LIBRARY
ATTN DAMA-CSM-N LTC E. DEBOESER JR

COMMANDER
HARRY DIAMOND LABORATORIES
WASHINGTON D.C. 20438
ATTN AMXDO-NP
ATTN AMXDO-TI TECH LIB

DIRECTOR
U S ARMY BALLISTIC RESEARCH LABS
ABERDEEN PROVING GROUND, MD 21005
ATTN TECH LIB E. BAICY

COMMANDER
U S ARMY COMM COMMMAND
FORT HUACHUCA, AZ 85613
ATTN TECHNICAL LIBRARY

COMMANDER
U S ARMY MAT + MECHANICS RSCH CTR
WATERTOWN, MA 02172
ATTN R SHEA

COMMANDER
U S ARMY NUCLEAR AGENCY
FORT BLISS, TX 79916
ATTN TECH LIB

COMMANDER
U S ARMY WEAPONS COMMAND
ROCK ISLAND ARSENAL
ROCK ISLAND, IL 61201
ATTN TECHNICAL LIBRARY

CHIEF OF NAVAL MATERIAL
NAVY DEPT
WASHINGTON D.C. 20360
ATTN MAT 0323

CHIEF OF NAVAL OPERATIONS
NAVY DEPARTMENT
WASHINGTON D.C. 20350
ATTN OP 03FG
ATTN OP 985F

CHIEF OF NAVAL RESEARCH
DEPARTMENT OF THE NAVY
ARLINGTON VA 22217
ATTN N PERRONE CD 474
ATTN TECHNICAL LIBRARY

OFFICER IN CHARGE
CIVIL ENGR LAB
NAVAL CONST. BATTALION CTR
PORT HUENEME CA 93041
ATTN R ODELLO
ATTN TECH LIB

COMMANDER
NAVAL ELECTRONIC SYSTEMS COMMAND
NAVAL ELECTRONIC SYSTEMS COMMAND HQS
WASHINGTON D.C. 20360
ATTN PME 117-21A

COMMANDER
NAVAL FACILITIES ENGINEERING COMMAND
HEADQUARTERS
WASHINGTON D.C. 20390
ATTN TECHNICAL LIBRARY

SUPERINTENDENT
NAVAL POSTGRADUATE SCHOOL
MONTEREY CA 93940
ATTN CODE 2124 TECH RPTS LIBRARIAN

DIRECTOR
NAVAL RESEARCH LABRATORY
WASHINGTON D.C. 20375
ATTN CODE 2027 TECHNICAL LIB
ATTN CODE 840 J GREGORY
ATTN CODE 8440 F ROSENTHAL
ATTN CODE 8403 R BELSHEIM
ATTN CODE 8403A G OHARA
ATTN CODE 8442 H HUANG

COMMANDER
NAVAL SEA SYSTEMS COMMAND
NAVY DEPARTMENT
WASHINGTON D.C. 20362
ATTN ORD - 91313 LIB
ATTN CODE 03511 C POHLER

COMMANDER
NAVAL SHIP RSCH AND DEVELOPMENT CTR
UNDERWATER EXPLOSIONS RSCH DIVISION
PORTSMOUTH V.A. 23709
ATTN E PALMER
ATTN TECHNICAL LIBRARY

COMMANDER
NAVAL SHIP ENGINEERING CENTER
CENTER BUILDING
HYATTSVILLE MD 20782
ATTN NSEC 6120D
ATTN NSEC 6110.01
ATTN NSEC 6105G
ATTN NSEC 6105
ATTN 6105C1
ATTN TECHNICAL LIBRARY

COMMANDER
NAVAL SHIP RESEARCH AND DEV CENTER
BETHESDA MD 20034
ATTN CODE 17 WW MURRAY
ATTN CODE 142-3 LIBRARY
ATTN CODE 174 R SHORT
ATTN CODE 11
ATTN CODE 2740 Y WANG
ATTN CODE 1962
ATTN CODE 1903
ATTN CODE 1731C
ATTN CODE 1171
ATTN CODE 19

COMMANDER
NAVAL SURFACE WEAPONS CENTER
WHITE OAK
SILVER SPRING MD 20910
ATTN CODE 241 J PETES
ATTN CODE 1224 NAVY NUC PRGMS OFF
ATTN CODE 730 TECH LIB
ATTN CODE 240 H SNAY
ATTN CODE 243 G YOUNG

COMMANDER
NAVAL SURFACE WEAPONS CENTER
DAHLGREN LABORATORY
DAHLGREN VA 22448
ATTN TECHNICAL LIBRARY

COMMANDER
NAVAL UNDERSEA CENTER
SAN DIEGO, CA 92152
ATTN TECHNICAL LIBRARY

COMMANDER
NAVAL WEAPONS CENTER
CHINA LAKE CA 93555
ATTN CODE 533 TECH LIB

COMMANDING OFFICER
NAVAL WEAPONS EVALUATION FACILITY
KIRTLAND AIR FORCE BASE
ALBUQUERQUE NM 87117
ATTN TECHNICAL LIBRARY

DIRECTOR
STRATEGIC SYSTEMS PROJECTS OFFICE
NAVY DEPARTMENT
WASHINGTON D C 20376
ATTN NSP-272
ATTN NSP-43 TECH LIB

AF CAMBRIDGE RSCH LABS, AFSC
L.G. HANSCOM FIELD
BEDFORD MA 01730
ATTN SUOL AFCRL RSCH LIB

HEADQUARTERS
AIR FORCE SYSTEMS COMMAND
ANDREWS AFB
WASHINGTON D C 20331
ATTN TECHNICAL LIBRARY

COMMANDER
ARMAMENT DEVELOPMENT&TEST CENTER
ELGIN AFB FL 32542
ATTN TECHNICAL LIBRARY

LOS ALAMOS SCIENTIFIC LAB
P O BOX 1663
LOS ALAMOS NM 87544
ATTN DOC CONTROL FOR REPORTS LIB

SANDIA LABS
LIVERMORE LAB
P O BOX 969
LIVERMORE CA 94550
    ATTN DOC CON FOR TECH LIB

SANDIA LABORATORIES
P.O. BOX 5800
ALBUQUERQUE NM 87115
    ATTN DOC CON FOR 3141 SANDIA RPT COLL

U S ENERGY RSCH & DEV ADMIN
DIVISION OF HEADQUARTERS SERVICES
LIBRARY BRANCH G-043
WASHINGTON D C 20545
    ATTN DOC CONTROL FOR CLASS TECH LIB

UNIV OF CALIFORNIA
LAWRENCE LIVERMORE LAB
P.O. BOX 808
LIVERMORE CA 94550
    ATTN TECHNICAL LIBRARY

AGBABIAN ASSOCIATES
250 NORTH NASH STREET
EL SUGONDO CA 90245
    ATTN M AGBABIAN

BATTELLE MEMORIAL INSTITUTE
505 KING AVENUE
COLUMBUS OH 43201
    ATTN TECHNICAL LIBRARY

BELL TELEPHONE LABORATORIES INC.
MOUNTAIN AVE
MURRAY HILL NJ 07974
ATTN TECH RPT CTR

BOEING COMPANY
P.O. BOX 3707
SEATTLE WA 98124
ATTN AEROSPACE LAB

CAMBRIDGE ACOUSTICAL ASSOC
1033 MASSACHUSETTS AVE
CAMBRIDGE MA 02138
ATTN M JUNGER

CIVIL / NUCLEAR SYSTEMS CORP
1200 UNIVERSITY N. E.
ALBUQUERQUE NM 87102
ATTN T DUFFY

ELECTRIC BOAT DIV
GENERAL DYNAMICS CORP.
GROTON CN 06340
ATTN L. CHEN

GENERAL ELECTRIC CO.
TEMPO-CENTER FOR ADVANCED STUDIES
816 STATE STREET (P.O. DRAWER QQ)
SANTA BARBARA CA 93102
ATTN DASIAC

ITT RESEARCH INST
10 WEST 35TH ST
CHICAGO IL 60616
ATTN TECHNICAL LIBRARY

INST FOR DEFENSE ANALYSIS
400 ARMY NAVY DRIVE
ARLINGTON VA 22202
ATTN IDA LIBRARIAN R SMITH

J.L. MERRITT
CONSULTING + SPECIAL ENGR SVS INC
P.O. BOX 1206
REDLANDS CA 92373
ATTN TECHNICAL LIBRARY

KAMAN AVIDYNE
DIV OF KAMAN SCEINCES CORP
83 SECOND AVE
NW INDUSTRIAL PARK
BURLINGTON MA 01803
ATTN E CRISCIONE
ATTN TECHNICAL LIBRARY
ATTN G ZARTARIAN

KAMAN SCIENCES CORP.
P.O. BOX 7463
COLORADO SPRINGS CO 80933
ATTN TECHNICAL LIBRARY

LOCKHEED MISSILES AND SPACE CO.
3251 HANOVER ST
PALO ALTO CA 94304
ATTN TECH INFO CTR D/COLL
ATTN T GEERS D/52-33 BLDG 205

NATHAN M. NEWMARK
CONSULTING ENGINEERING SERVICES
1114 CIVIL ENGINEERING BLDG
URBANA IL 61801
ATTN N NEWMARK

POLYTECHNIC INST OF NEW YORK
DEPT OF APPLIED MECH
333 JAY STREET
BROOKLYN NY 11201
ATTN J KLOSNER

R+D ASSOCIATES
P.O. BOX 3580
SANTA MONICA CA 90403
ATTN TECHNICAL LIBRARY

STANFORD RESEARCH INST
333 RAVENSWOOD AVE
MENLO PARK CA 94025
ATTN SRT LIB ROOM G021
ATTN B GASTEN
ATTN G ABRAHAMSON

TETRA TECH INC.
630 N ROSEMEAD BLVD
PASEDENA CA 91107
ATTN LI-SAN HWANG
ATTN TECH LIB

THE BDM CORP
1920 ALINE AVE
VIENNA VA 22180
ATTN TECH LIB

UNIV OF MARYLAND
DEPT OF CIVIL ENGR
COLLEGE PARK MD 20742
ATTN B BERGER

URS RESEARCH CO.
155 BOVET RD.
SAN MATEO CA 94402
ATTN TECH LIB

WEIDLINGER ASSOCIATES
3000 SAND HILL ROAD
BUILDING 4 SUITE 245
MENLO PARK CA 94025
ATTN J. ISENBERG

WEIDLINGER ASSOCIATES
110 EAST 59TH STREET
NEW YORK, NY 10022
ATTN DR. M. BARON

ASSISTANT CHIEF FOR TECHNOLOGY
OFFICE OF NAVAL RESEARCH
ARLINGTON, VIRGINIA 22217
ATTN CODE 200

TELEDYNE BROWN ENG.
MAIL STOP 44
300 SPARKMAN DRIVE
RESEARCH PARK
HUNTSVILLE, ALABAMA 35807
ATTN DR. MANU PATEL

DIRECTOR
U S ARMY WATERWAYS EXPERIMENT STN
P.O. BOX 631
VICKSBURG MS 39180
ATTN J STRANGE
ATTN W FLATHAU
ATTN TECH LIB (UNCL ONLY)

AF INSTITUTE OF TECHNOLOGY, AU
WRIGHT PATTERSON AFB, OH 45433
ATTN LIB AFIT BLDG 640 AREA B(UNCL ONLY)

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) On Improving and Extending the Design Shock Spectra used in DDAM		5. TYPE OF REPORT & PERIOD COVERED TECHNICAL NOTE
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Frank L. DiMaggio and David Ranlet		8. CONTRACT OR GRANT NUMBER(s) N00014-72-C-0119
9. PERFORMING ORGANIZATION NAME AND ADDRESS Weidlinger Associates 110 East 59th Street New York, New York 10022		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 61153N RR 023-03 064464
11. CONTROLLING OFFICE NAME AND ADDRESS Department of the Navy Office of Naval Research Arlington, Virginia 22217		12. REPORT DATE September 1976
		13. NUMBER OF PAGES 8
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; Distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

This project is sponsored by the joint DNA/ONR/NAVSEA program in "Advanced Submarine Shock Survivability in Underwater Nuclear Attack".

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Shock Loading
Design Shock Spectra
Internal Structure

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A method is presented which may be used to improve and extend the design shock spectra used in the Dynamic Design Analysis Method (DDAM).

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-014-6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

UNCLASSIFIED